Economic analysis of HRS network build-up in the Netherlands

Marcel Weeda

Petten
3 July 2015
ECN-E—15-067

Acknowledgement and Preface

- ## Acknowledgement

This study was commissioned by the Ministry of Infrastructure and the Environment, and was supervised by Mr. A. Hablé of the Ministry. The study was conducted by Mr. M. Weeda of ECN, where the study is registered under project number 5.3756. The author thanks Mr. S. Lensink of ECN for his help in carrying out the economic evaluation, and determining financial gaps according to the methodology used for the Dutch SDE-regulation (promotion sustainable energy).

- ## Preface

This report updates a previous version of the 'Economic analysis of HRS network build-up in the Netherlands ' (31 March 2015). This work has been subject of discussion with industry stakeholders. The feedback received during these discussion has been processed in the present update. Interpretation of the feedback into new starting points, assumptions and parameter values has been the responsibility of the author. The document thus does not represent the view of the industry. Stakeholders that have been consulted are:

- Air Liquide;	Jaap Oldenziel
- Air Products;	Frank Schnitzeler
- AKZONobel:	Joost Sandberg
- CNG-net;	Erik Butkher
- HyGear:	Ellart de Wit
- Linde:	Jaco Reijerkerk
- NOW (Germany):	Hanno Butsch
- Shell:	Alice Elliot
- Siemens en Stedin:	Jaap Bolhuis en Patrice Pawroredjo

Abstract

- Abstract

This study evaluates the economics of a network of hydrogen refuelling stations in the Netherlands. Ambitions for deployment of fuel cell cars for the period 2017-2030, as defined within the framework of the national 'Visions on Sustainable Fuels' project and the European TEN-T 'Hydrogen Infrastructure for Transport' project, have served as starting point for the evaluation.

A hydrogen station network has been evaluated, resulting from installation of discrete station sizes determined in accordance with an assumed maximum level of utilisation for the growing network. The initial network is built up in four year and comprises 20 stations. This network gradually grows to approximately 200 stations in 2030, which is considered sufficient for nationwide coverage.

Results indicate a significant financial gap that need to be bridged by involved stakeholders. In addition to the size of the investment costs, the financial gap of the hydrogen stations is strongly influenced by the cost of hydrogen production and the level of excise duty on hydrogen, on the one hand, and the maximum sales price of hydrogen based on the benchmark case (e.g. diesel cars complying to 95 gCO_2/km), on the other hand. These factors determine the available price margin for covering of operations and maintenance costs and capital costs, and for recovery of investment costs.

Without any policy intervention, the financial gap is estimated to be about € 84 million, resulting from negative annual operating cash flows for a period of more than 10 years. Due to the large uncertainties related to this new zero-emission option for transport, the required investments are associated with considerable risks. Therefore, significant policy support will likely be needed to spur industry stakeholders on investing in build-up of the initial network of hydrogen stations.

Content

Introduction and background

Rationale: what again was the reason for hydrogen mobility?

ECN

- The transport sector is in need of cleaner and much more efficient vehicles, and of alternative low-carbon fuels, in order to:
  - Mitigate transport related air pollution problems. Emissions from the combustion of fuels in engines, especially ultrafine particles, appear to have a profound negative impact on public health leading to considerable health related costs due to premature death, sick leave and reduced labor productivity.
  - Significantly reduce the CO_2 footprint of transport. The transport sector accounts for 20-25% of CO_2 emissions, with the vast majority coming from road transport. While trends should be downwards in view of the required worldwide CO_2 emission reduction to combat irreversible and harmful climate change, CO2 emissions of transport in the Netherlands, Europe and globally are still increasing..
  - Improve energy security and reduce oil dependence of the transport sector. This is important because a well-functioning transport sector is one of the major drivers for economic growth and societal development.

- Hydrogen as a fuel for efficient zero-emission fuel cell electric vehicles (FCEVs) is one of the main alternatives for future road transport and mobility:
  - Hydrogen FCEVs are one of only two truly zero-emission vehicle options, i.e. no tail-pipe emissions
  - FCEVs combine the comfort and benefits of electric driving (silent and efficient) with the convenience of incumbent cars in terms of vehicle range and refuelling time (typically >400-500 km on a single refuelling in 3-5 minutes). When produced at volume, hydrogen FCEVs are projected to have cost similar to hybrid electric vehicles (HEVs), and significantly less than BEVs for the same vehicle range.
  - Hydrogen and fuels cells are well-suited to electrify a wide range of road vehicles, ranging from small cars to buses and light duty trucks, and potentially even heavy duty trucks in the more distant future.

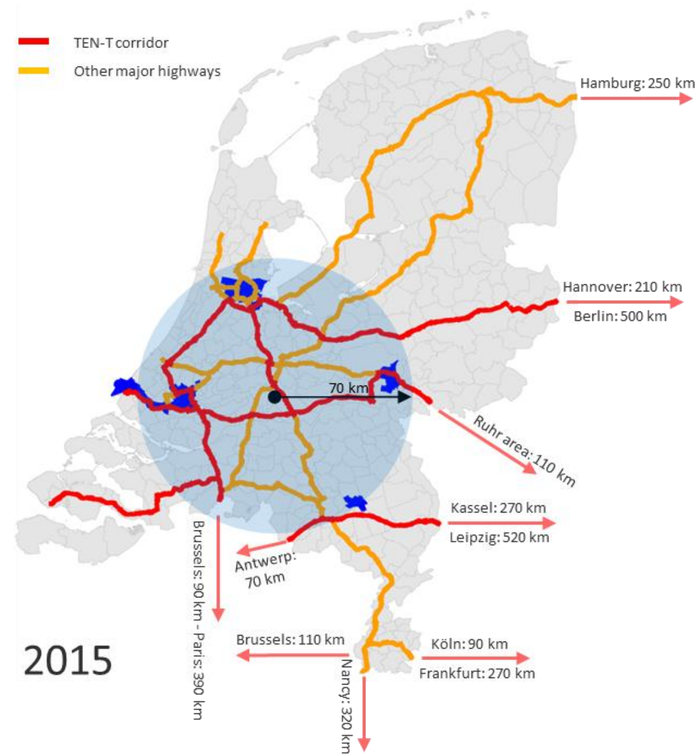
Rationale continued, and status of hydrogen mobility

- Hydrogen as a fuel for efficient zero-emission fuel cell electric vehicles (FCEVs) is one of the main alternatives for future road transport and mobility (continued):
  - Hydrogen can be produced completely CO_2-free; it can be produced by electrolysis of water, using electricity from renewable energy sources, such as wind, solar and hydro-power, and it can also be produced with near net zero-carbon emissions from biomass sources. In a transition period from fossil to renewable energy, hydrogen could also be produced from fossil fuels via reformation, and play a role in the de-carbonization of these sources by using Carbon Capture and Storage (CCS), to sequester the resulting concentrated CO_2-stream of the production processes.
  - Hydrogen is a versatile energy carrier, which together with electricity could provide the backbone of the future energy system. Production by electrolysis offers a mechanism to facilitate extensive penetration of intermittent renewables into the energy system. The technology is modular, and can support the integration in local, regional, as well as central schemes. Since it is a gas it can be easily distributed and stored, and it can be used in a wide range of energy and industry applications.

- Status of hydrogen mobility:
  - Significant progress has been made towards commercialization of hydrogen as an alternative fuel for transport in the last decade, most notably for cars, buses, refuelling infrastructure and related standards.
  - FCEVs, especially cars, are technically ready for commercialization; market development rather than technology development is currently the main barrier for market introduction of hydrogen and FCEVs.
  - Hydrogen delivery technology and pathways, and in particular hydrogen refuelling stations, have been demonstrated and tested, and are ready for scale-up to build initial networks
  - Market development initiatives are spreading in the USA, in Asia and in Europe, including in the Netherlands.

Favourable conditions for a role in a leading group of EU-countries

- Unique selling points for early market development in the Netherlands:
  - High population/market density
  - High GDP per capita/purchasing power
  - Large hydrogen industry
  - Centrally located in NW-Europe, well connected to DE, DK, BE, FR and UK
  - Strong track record for early and wide adoption of innovative clean cars, e.g.:
    - largest share of hybrids in EU
    - forerunner in plug-in cars



Objective and scope

Economic analysis: Objective and scope

- Objective:
  - Obtaining an order of magnitude estimate for the financial gap that needs to be bridged in the build-up phase of a hydrogen refuelling infrastructure for fuel cell electric vehicles (FCEVs).

- Scope:
  - The Netherlands
  - Hydrogen refuelling station (HRS) network for cars that refuel 700 bar hydrogen
  - HRS complying to prevailing standards SAE J2601 and SAE J2799, and all other standards as described in the PGS-richtlijn 35: Waterstofafleverinstallaties
  - Fuel cell car fleet scenario and HRS network development as discussed within the framework of the hydrogen roundtable as part of the Dutch "Vision on sustainable fuels for transport" project and the hydrogen National Implementation Plan

- Not within the scope:
  - Price of fuel cell cars and total cost of ownership (TCO) analysis for cars
  - HRS for fuel cell buses; buses only need 350 bar stations, which are generally cheaper than 700 bar stations
  - Price of fuel cell buses and evaluation of cost per kilometer for fuel cell buses

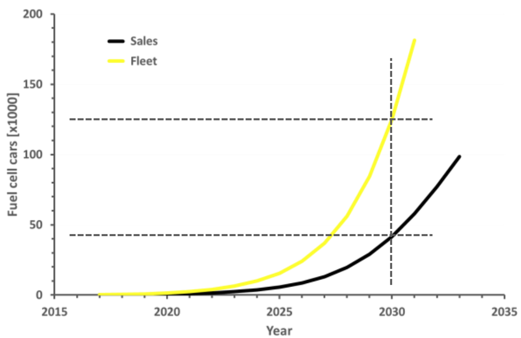
Definition and characteristics of the hydrogen refuelling station network

Introduction period in 3 stages before commercial mass market is reached

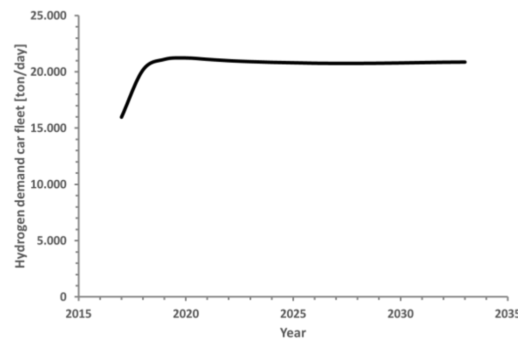
	2015 – 2020 Market preparation	2020 – 2025 Early market introduction	2025 – 2030 Full market introduction
Objectives	• Build-up initial HRS network, and introduction first FCEV fleets • Gain practical experiences • Develop appropriate supportive financial and regulatory frameworks • Inform and engage authorities • Inform the public	• Evaluation experiences, and implement advancing insights in financial and regulatory frameworks • Expand initial HRS network to a network that fully spans the main national roads	• Access to hydrogen at a short distance for ≥ 90% of the people • Gradual phasing out of support measures in line with costs and market developments
Network coverage	• Limited number of strategically located major cities • Focus on TEN-T corridors and early connection to neighboring markets	• All very strongly and strongly urbanized areas	• All areas except non-urban, rural areas
Market (segments)	• Local/-regional fleets with a need for cars with a large range - Government fleets - High-end business market - Captive fleets (e.g. taxi's) • Buses	• Expansion existing segments, with widening of deployment in business market • Start private car market, including used cars • Speciality vehicles • Delivery vans (if available)	• Expansion existing markets • Delivery vans and small trucks

Data and scenarios underlying specific HRS network build-up

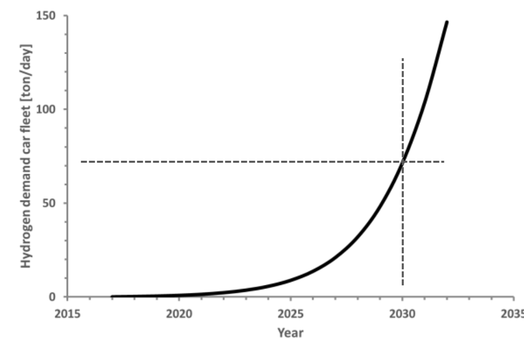
Fuel cell car sales and fleet scenario



Average mileage FCEVs



Development hydrogen demand

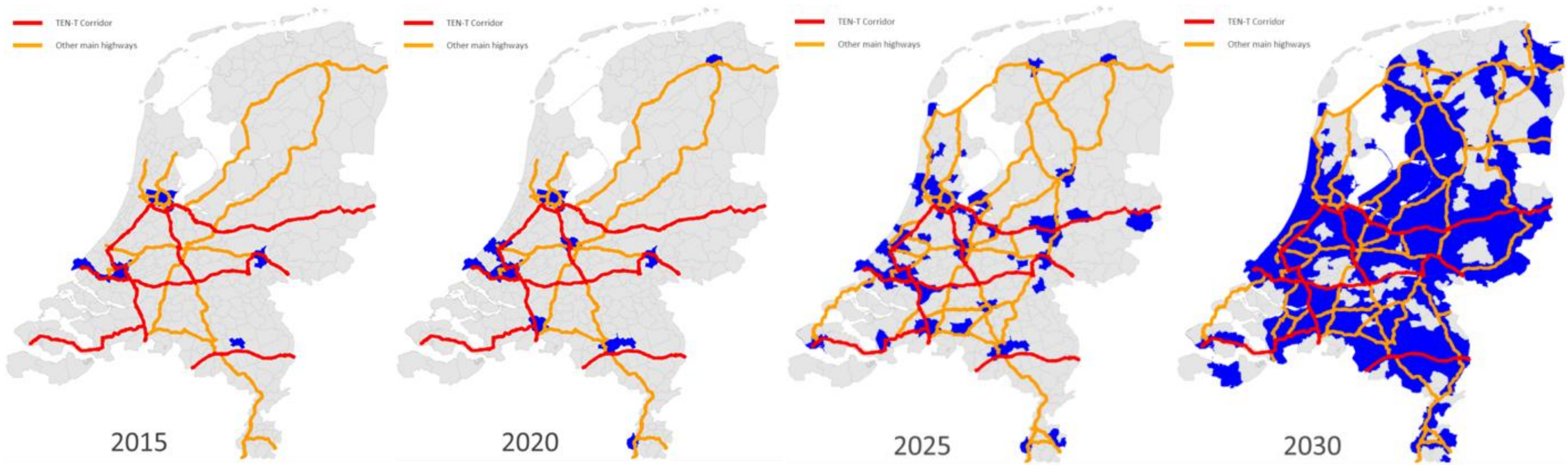


- Development fuel cell car fleet based on:
  - Scenario fuel cell car sales (ECN market analysis)
  - Loss of cars curve (CBS statistics)

- Development average mileage of a FCEV based on:
  - 50% replaces diesel cars and 50% replaces gasoline cars
  - Fuel cell car fleet scenario
  - CBS data on annual mileage of cars per fuel and car age

- Development hydrogen demand by fuel cell cars based on:
  - Fuel cell car fleet scenario
  - Average mileage of FCEVs
  - Fuel consumption in practice: 1 kg/100km, assumed constant in the analysis

Rollout HRS network along TEN-T corridors and national roads

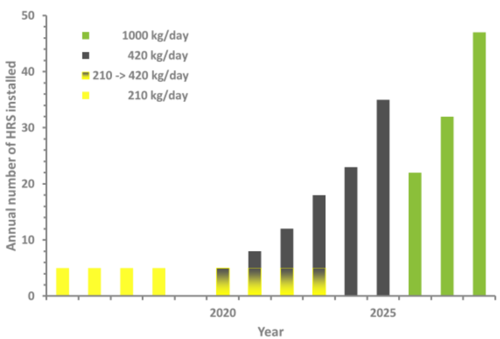


	Market preparation	Early market introduction	Full market introduction	Mass market
Car fleet	Few → 1,500	1,500 → 15,000	15,000 → 125,000	→ > 2.5 mln
HRS network	2 → 20	20 → 50	50 → 200	→ > 1,000
Population	3.3 mln (20%)	8.0 mln (50%)	15.0 mln (90%)	(100%)

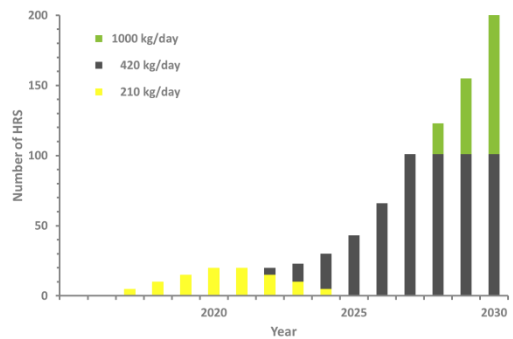
HRS network build-up, and utilisation

- Boundary conditions for design of the HRS network resulting from the fuel cell car sales scenario:
  - Initial network of 20 HRSs available in 2020: 5 stations each year in the period 2017-2020
  - Country-wide availability of hydrogen by 2030, which requires about 200 HRS (~5% of current refuelling stations)
  - Maximum average HRS network utilisation up to 2030 is 50% (based on HRS peak capacity)
- “Design rules” for development of the HRS network:
  - Initial netwerk of 20 HRS with 210 kg/day stations
  - Upgrade of initial stations to 420 kg/day 5 years after installation ,and installation additional 420 kg/day based on need for HRS capacity resulting from hydrogen demand and network utilisation
  - Shift to installation of larger capacity HRS determined by target of approximately 200 HRS in 2030

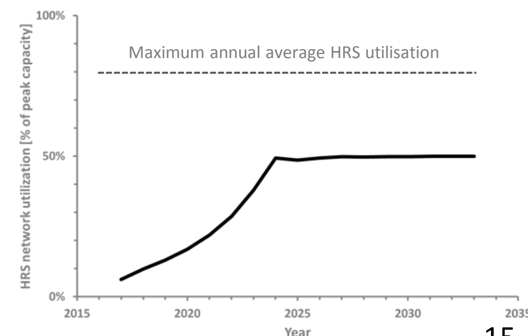
HRS deployment scheme



HRS network development



HRS network utilisation



Potential sales margin on hydrogen: Price and Costs

Maximum sales price of hydrogen at the HRS

Parameter	units	Gasoline	Diesel	Remark
Oil price	$/barrel	100		
	€/barrel	83		1.2 $/€
	€/GJ	14.5		5.74 GJ/barrel
Production	€/l	0.60	0.62	159,987 l oil/barrel; efficiency to gasoline 86%, and 84% to diesel
Distribution & margin	€/l	0.19	0.18	Average 2012 - 2014
Excise duty	€/l	0.77	0.48	Netherlands, 2015
Pump price ex. VAT	€/l	1.56	1.28	
	€/GJ	48.6	35.6	Gasoline: 32.2 MJ/l; Diesel 35.9 MJ/l
Maximum H_2 sales price ex. VAT	€/GJ	76.4	54.9	95 gCO_2/km is comparable to 4.1 l/100 km gasoline and 3.6 l/100km diesel; FCEV drive-cycle H2 consumption assumed 0.7 kg/100km; efficiency improvement FCEV is 36% and 35% compared to gasoline and diesel, respectively [ECN analysis based on JEC-reports]
Assumption for analysis	€/kg	9.2	6.6	Hydrogen: 120 MJ/kg

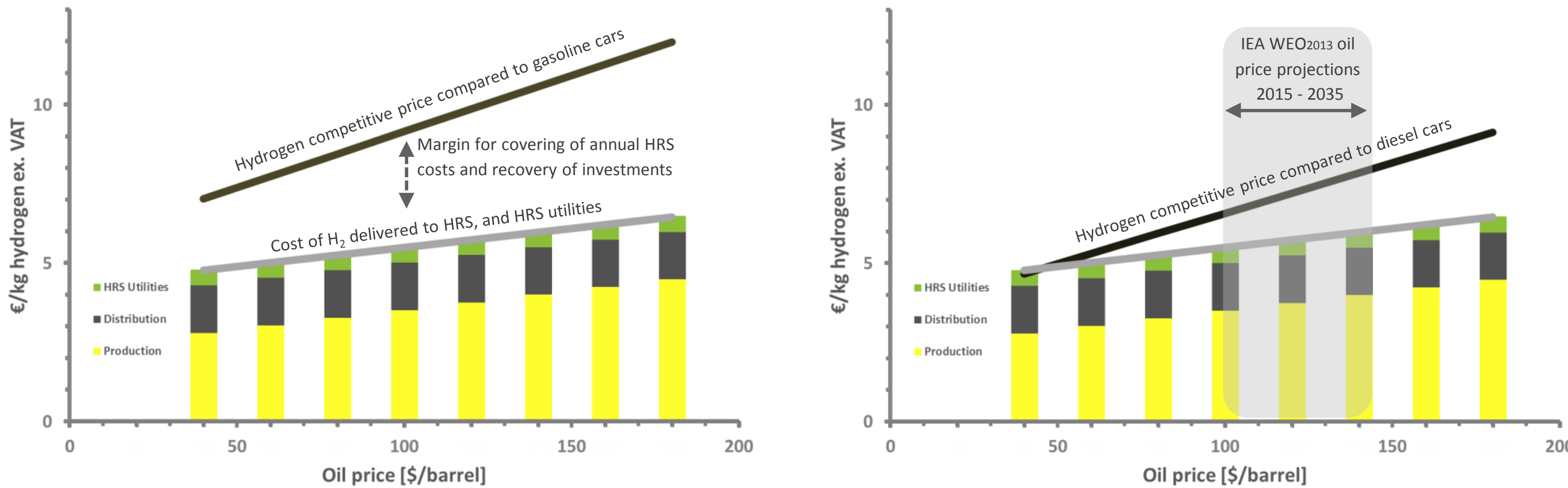
- The maximum sales price of hydrogen, in order to be competitive on a fuel cost per kilometer basis, varies significantly depending on whether gasoline or diesel is taken as the benchmark
- The diesel benchmark poses a much larger challenge for the supply of competitive hydrogen than gasoline

Cost of hydrogen up to the pump excluding HRS CAPEX and O&M

Parameter	units	Hydrogen	Remark
Oil price	€/GJ	14.5	$100/barrel
Natural gas price	€/GJ	8.1	Indicative equivalent price of natural gas [IEA WEO, 2013]; same order of magnitude as todays price
Cost of H_2 (@plant gate)	€/kg	3.5 –> 3.0	Short term -> 2030 cost of hydrogen for HRS from large-scale SMR (Steam Methane Reforming), excluding delivery to the HRS; cost decrease due to value chain optimisation and competition
Handling and distribution	€/kg	1.5 -> 1.0	Short term -> 2030 cost of delivery for trucked hydrogen
Cost of H_2 delivered at HRS		5.0 –> 4.0	FCH-JU target for H2 delivered at HRS is 5.0 €/kg as a minimum up to 2020 and 4.5 €/kg for 2023!!
Utilities (mainly electricity)	€/kg	0.5	Compression and refrigeration at HRS: overall order of magnitude 5 kWh/kg @ 10 €ct/kWh.
Assumption for analysis	€/kg	5.5 -> 4.5	Short term -> 2030 H_2 pump price **excluding** contribution of HRS CAPEX, equipment O&M, land use (fees), overhead, margins etc.

- No contribution for CO_2 price included; impact would, however be limited with contribution of roughly €0.04/kg H_2 for each €10/ton CO_2

Comparison of H_2 pump price and direct cost of H_2 for an HRS

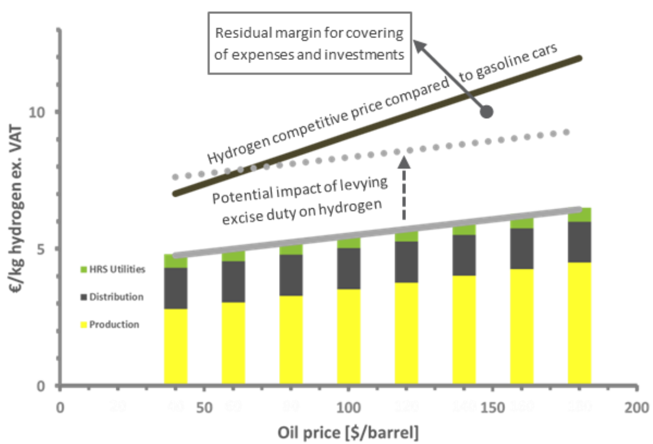


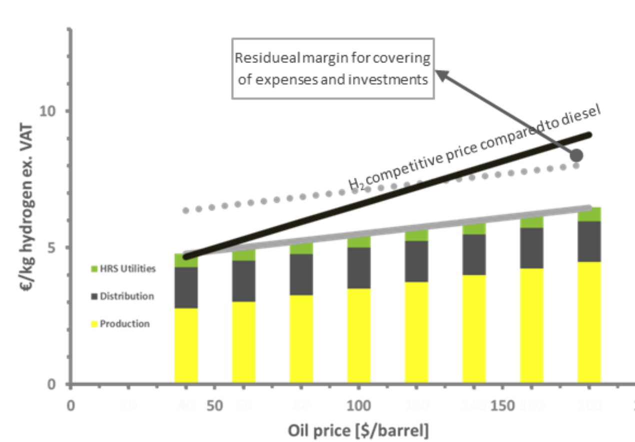
- Observations:
  - The direct cost of H_2 for a HRS (cost of H_2 delivered to HRS and cost of utilities for compression/refrigeration at the HRS) already consume a significant part of the room for competitive H_2 pricing at the pump; these costs need to be minimized!
  - Diesel is a much more challenging benchmark than gasoline, leaving little room for covering of HRS expenses and investments
  - Improvement of the FCEV fuel efficiency relative to the benchmark improves the room for covering of HRS costs, and vice versa
  - Increasing oil prices offer an increasing margin for covering of annual HRS expenses, and recovery of investments

Potential impact of excise duty on the H_2 price margin for a HRS

Parameter	units	Gasoline	Diesel	Remark
Excise duty	€/l	0.77	0.48	Netherlands, 2015
H_2 excise duty equivalent	€/kg	2.9	1.6	Equal tax on energy basis, i.e. equal €/MJ_{final}
Cost of hydrogen for HRS excluding excise duty	€/kg	5.5 → 4.5	5.5 → 4.5	Short term → 2030 cost of hydrogen delivered to the HRS and utilities at HRS for compression and refrigeration
Cost of hydrogen for HRS including excise duty	€/kg	8.4 → 7.4	7.1 → 6.1	Short term → 2030 idem as above, but including a contribution of excise duty
Competitive H_2 sales price ex. VAT	€/kg	9.2	6.6	Price to be competitive on the basis of fuel cost per kilometer

- Levying excise duty significantly reduces the potential to cover annual O&M costs and recover the HRS investment.





Comparison of hydrogen production costs of different production options

Hydrogen production cost large-scale SMR and byproduct hydrogen

- The hydrogen production cost represents the cost directly related to the production facility. This is only part of the total cost of hydrogen. In addition, the total cost of hydrogen is not the same as the price of hydrogen. The price for which hydrogen is delivered to an HRS, is a cost for the HRS.

Hydrogen production cost from central large-scale Steam Methane Reforming (SMR):

Parameter	units	Hydrogen	Remark
Oil price	€/GJ	5.8 – 26.1	Oil price ranging from $40 – 180/barrel; 1.2 $/€; 5.74 GJ/barrel
Natural gas price	€/GJ	3.2 – 14.5	Ratio of oil and natural gas price assumed 1.8 [IEA WEO, 2013]
Cost of H_2 production	€/GJ	8.4 – 22.5	Conversion efficiency natural gas into H_2 is assumed 80%; Share of natural gas cost in cost of H_2 is assumed 70%
Cost of H_2 production	€/kg	1.0 – 2.7	Hydrogen: 120 MJ/kg

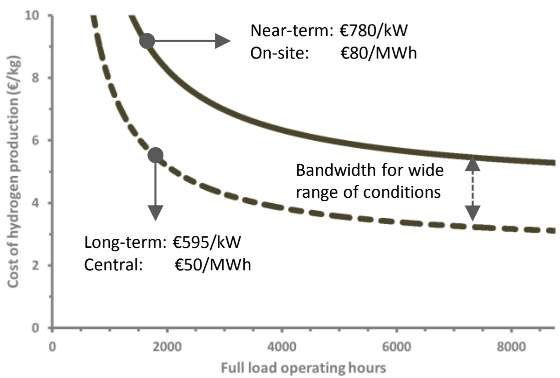
- The hydrogen production cost from large-scale SMR amount to €1.0-2.7/kg for a wide range of natural gas prices, equivalent to oil prices ranging from $40-180/barrel. At $100/barrel the cost will be in the order of €1.7/kg

- Hydrogen is a by-product in the chlor-alkali electrolysis proces for the production of Chlorine. The cost of hydrogen production is arbitrary ; it depends on the allocation of cost. The application will largely determine the cost, or price. If hydrogen has to compete with natural gas on a heating value basis the “cost” should be about €1/kg. For the purpose of fuel, hydrogen can be made available at a “cost” or price of €2-4/kg, which is similar to figures for hydrogen from large-scale SMR. By-product hydrogen potential in the Netherlands is in the order of 15 kton/yr (or 40 ton/day).

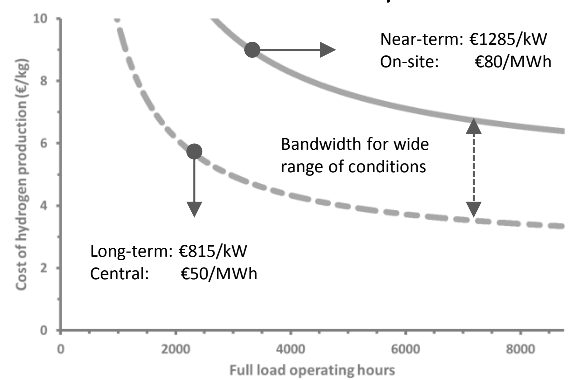
Hydrogen production via water-electrolysis

Parameter		Unit	Near-term (2015-2020)	Medium-term (2020-2025)	Long-term (2025-2030)	Remarks
Alkaline electrolysis	System cost	€/kW$_e$	780	620	595	Values derived from 'FCH-JU (2014), Development of electrolysis in the European Union', and in line with targets in FCH-JU MAIP 2014-2020. Parameters for cost of hydrogen calculation: Installation factor of 1.2 for total investment cost; annual O&M costs is 4% of system cost; system lifetime of 15 years; WACC of 8%.
	Consumption	kWh/kg	55	50	50	
PEM electrolysis	System cost	€/kW$_e$	1285	935	815	
	Consumption	kWh/kg	60	55	50	

Alkaline Electrolysis



PEM electrolysis



Various potential options for cost reduction. But impact not yet clear:

- Operational strategy for electricity price minimisation in volatile price situations
- Additional revenue from compensation for balancing services
- Allocation of avoided cost for strengthening of the grid

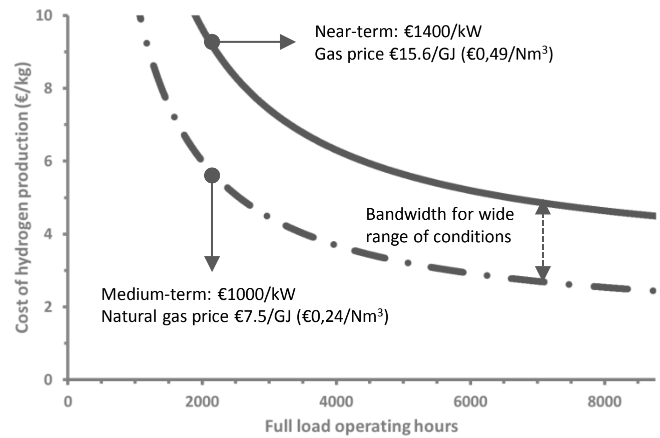
- Hydrogen production by electrolysis offers long-term prospects for production cost comparable to large-scale reforming of natural gas, but is considerably more expensive for the time being. By saving transport cost on-site production can be competitive if the electrolyser can be operated at high full load hours.

Distributed hydrogen production, e.g. from biogas

Parameter	Unit	Near-term (2015-2020)	Medium-term (2020-2025)	Remarks
Small-scale SMR system cost	€/kW_{th}	1400	1000	• System cost derived from FCH-JU MAIP 2014-2020; • Average Dutch non-household prices excluding / including taxes over the last 5 years (CBS) for category 1-10 TJ/a (near-term) and 10-100 TJ/a (medium-term); 10 TJ/a is equivalent to approximately 160 kg H_2/d. • Parameters for cost of hydrogen calculation: Installation factor of 1.2 for total investment cost; annual O&M costs is 4% of system cost; system lifetime of 15 years; WACC of 8%.
Efficiency (LHV)	-	63%	65%	
Natural gas/biogas price	€/GJ	9.2 / 15.6	7.5 / 11.2	

- In view of the excise duty issue it is not clear whether natural gas prices including or excluding energy taxes should be used; both cases are included in the graph.
- Green gas/biogas certificates to be able to produce “green” hydrogen would currently add €0.05/Nm^3 or €1.6/GJ to the natural gas price, resulting in about €0.3/kg H_2
- Production cost are significantly above large-scale SMR, but are lower than electrolysis. By saving transport cost on-site production can be competitive if the reformer can be operated at high full load hours.

Small-scale on-site Steam Methane Reforming



Evaluation of the economics of the HRS network

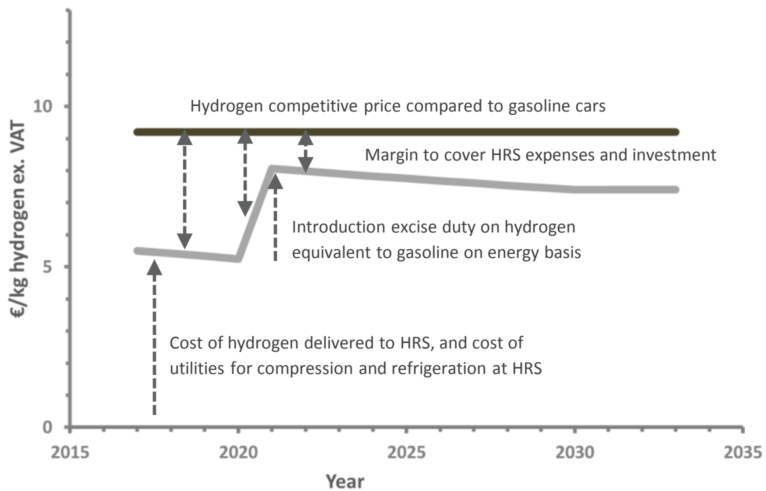
Assumptions HRS investment costs and annual O&M costs

- The network is built up with 210, 420 and 1000 kg/day stations:

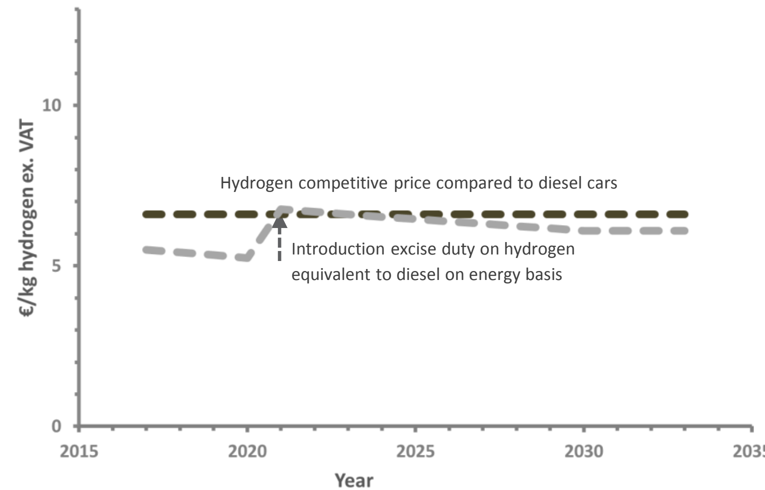
HRS size (peak capacity) kg/day	Max. average capacity kg/day	Indicative fleet size # cars	Type of costs		2015	2020	2025	2030
210	168	400	Equipment	[€ million]	0.8	0.7	0.5	0.4
			Total investment	[€ million]	1.2	1.0	0.8	0.7
			Specific investment	[€ per car]	3,000	2,500	2,100	1,600
			Annual O&M	[% of equipment]	25%	25%	20%	20%
420	336	800	Equipment	[€ million]	1.1	0.9	0.7	0.6
			Total investment	[€ million]	1.6	1.3	1.1	0.9
			Specific investment	[€ per car]	2,000	1,700	1,400	1,100
			Annual O&M	[% of equipment]	20%	20%	15%	15%
1000	700	1600	Equipment	[€ million]	1.5	1.3	1.0	0.8
			Total investment	[€ million]	2.2	1.8	1.5	1.2
			Specific investment	[€ per car]	1,400	1,150	950	750
			Annual O&M	[% of equipment]	15%	15%	10%	10%

Cost and price scenarios and parameters for economic analysis

- Case: gasoline is the benchmark for hydrogen



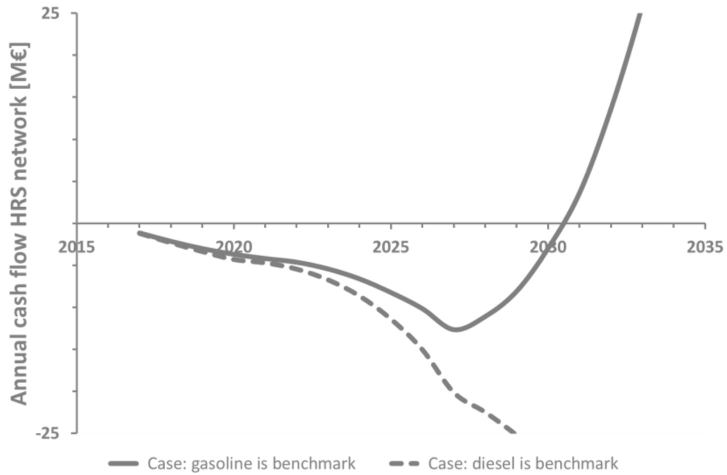
Case: diesel is the benchmark for hydrogen



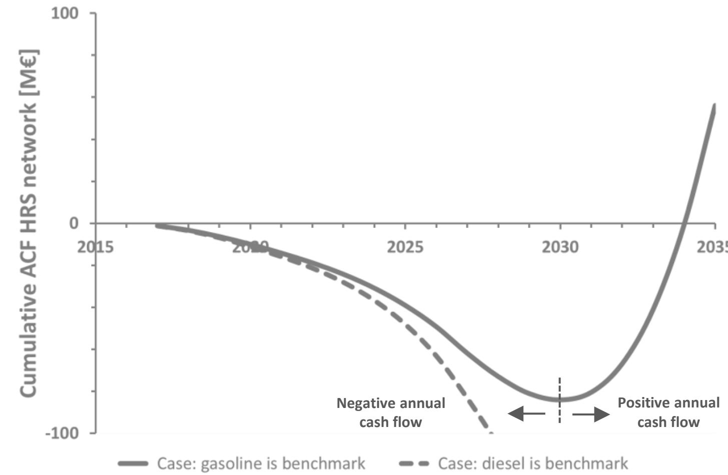
- Methodolgy for Subsidy Sustainable Energy (SDE) to calculate the financial gap. SDE parameters:
  - Equity share: 20%
  - Required ROI: 15%
  - Debt share: 80%
  - Interest rate loan: 6%
  - Company tax: 25%
  - Duration loan: 15 years
  - Period of amortization: 15 years
  - Economic life equipment: 15 years

Base case results: annual and cumulative annual cash flow

- Annual cash flow base case: no policy intervention



Cumulative annual cash flow: no policy intervention



- Main results:
  - €250 million cumulative investments in HRS network to 2030 (202 HRS: average €1.24 million/HRS)
  - No positive annual cash flow possible if diesel is the benchmark for hydrogen, under simulated conditions
  - If gasoline is taken as benchmark, a positive annual cash flow results after 14 years;
  - The total negative cash flow amounts to €84 million, which is on average about €100,000/HRS/year.
  - The HRS network as a whole breaks even in 2034, but individual stations may still face a financial gap.

Summary of results and conclusions

Summary of results, and conclusions

- A HRS network to support a fleet of 125,000 fuel cell cars in 2030 requires about €250 million investment.
- The financial gap of the HRS network varies strongly with the price margin on hydrogen, which is affected by:
  - The “allowable” sales price of hydrogen as set by the benchmark, e.g. diesel for an optimized ICE-car complying to 95 gCO_2/km
  - Cost of H_2 for the HRS, consisting of cost of H_2 delivered to the HRS, and the utility costs for compression and refrigeration
  - The amount of excise duty on hydrogen
- Use of gasoline as benchmark for setting the hydrogen sales price at the pump offers a much better perspective for an acceptable HRS business case than diesel. The potential margin resulting from using diesel as benchmark is not sufficient to cover annual expenses, and recover the investment.
- Without support measures, also the use of a hydrogen sales price based on gasoline results in a significant financial gap. The gap is estimated to be about €84 million, with:
  - A negative operating cash flow for a period of about 14 years
  - An average negative annual operating cash flow of about €100,000/HRS/yr
  - Break even of operating cash flow at network level after about 18 years
- Results are on network level. Individual HRS may do better, but others will perform worse. Individual stations may still face a financial gap, even after 2030 due to a period of underutilization of a new HRS.
- Due to the large uncertainties related to hydrogen and fuel cell cars, the required investments are associated with considerable risks. Significant policy support will therefore likely be needed to spur industry stakeholders on investing in build-up of the initial network of hydrogen stations.

Discussion

HRS economics in perspective

- The difficult business case for HRSs is no exception; infrastructure for battery electric cars has the same problem, i.e. relatively high investment costs and underutilisation. Investment cost for a home charging point are currently about €1,250. A public charging point is at least double this amount. It is assumed that BEV require on average 1.3 charging points. This results in specific investment costs of at least €2,000 per BEV, which is comparable to the specific investment costs for the initial HRSs.

- A HRS supplies fuel to zero-emission cars that do not emit emission that cause health damage and have a negative climate impact. Avoided damage costs over the lifetime of a HRS are significant and could be added to the "value" of a HRS.
  - FCEV compared to Euro 6 diesel and gasoline cars emitting 95 gCO_2/km (Note: in practice emissions appear higher than the norm, and the difference between ICE and FCEV may be larger)
  - Average mileage company cars: 30,000 km for diesel cars and 10,000 km for gasoline cars
  - FCEVs replace 50% diesel cars and 50% gasoline cars
  - Projected damage cost of pollutants for 2020

Indicative avoided cost of climate impact and health damage related to a HRS

HRS size [kg/day]	Indicative fleet size [# cars]	Value avoided climate impact (WTW-basis) [€ million]	Value avoided health damage [€ million]	Total avoided costs [€ million]
210	400	0.25 – 0.30	0.15 – 0.20	0.35 – 0.40
420	800	0.40 – 0.45	0.35 – 0.40	0.75 – 0.80
1000	1600	0.85 – 0.90	0.70 – 0.75	1.5 – 1.6

Referenties:
- PBL (2008), Berekening van externe kosten van emissies voor verschillende voertuigen; tabel 1 – p.2 and tabel 6 – p.26
- CE Delft (2005), Luchtkwaliteit in Nederland; Enkele brandende vragen; tabel 2 – p.9
- CE Delft (2014), Externe en infrastructuurkosten van verkeer; Een overzicht voor Nederland in 2010.

Strategies and measures to reduce the financial gap

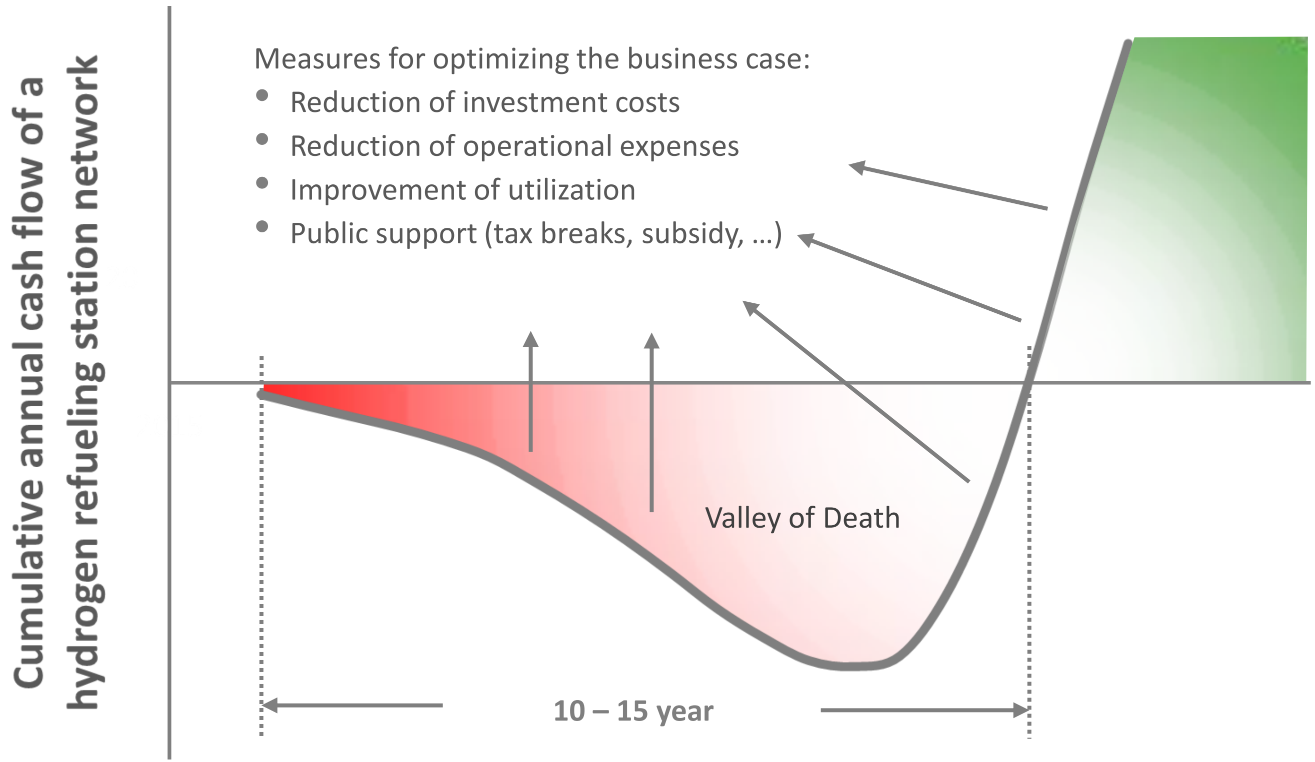
- Providing (direct and indirect) support from policy:
  - Investment support, e.g. through a grant, loans at favourable conditions and favourable tax treatment of investments
  - Contribution to covering of annual costs, e.g. through an annual allowance, a guaranteed purchase of hydrogen for government vehicles (government as launching customer), or programs to organise and support initial customers
  - Full or partial excise duty exemption for a certain period
  - Recognition of hydrogen mobility by governments, by including the option in strategies for reaching future sustainable mobility targets, and providing support for fuel cell vehicles to facilitate market introduction and development
  - Adaptive but consistent policy making, based on a long-term view, that seeks to optimise the investment climate by reducing policy induced market volatility (avoidance of sudden and major policy changes)

- From a Dutch perspective it is important to make the best use of European funds available for hydrogen and fuels cells (FCH-JU), and development of new infrastructures for alternative fuels (TEN-T CEF, ESFS – Juncker fund, EIB)

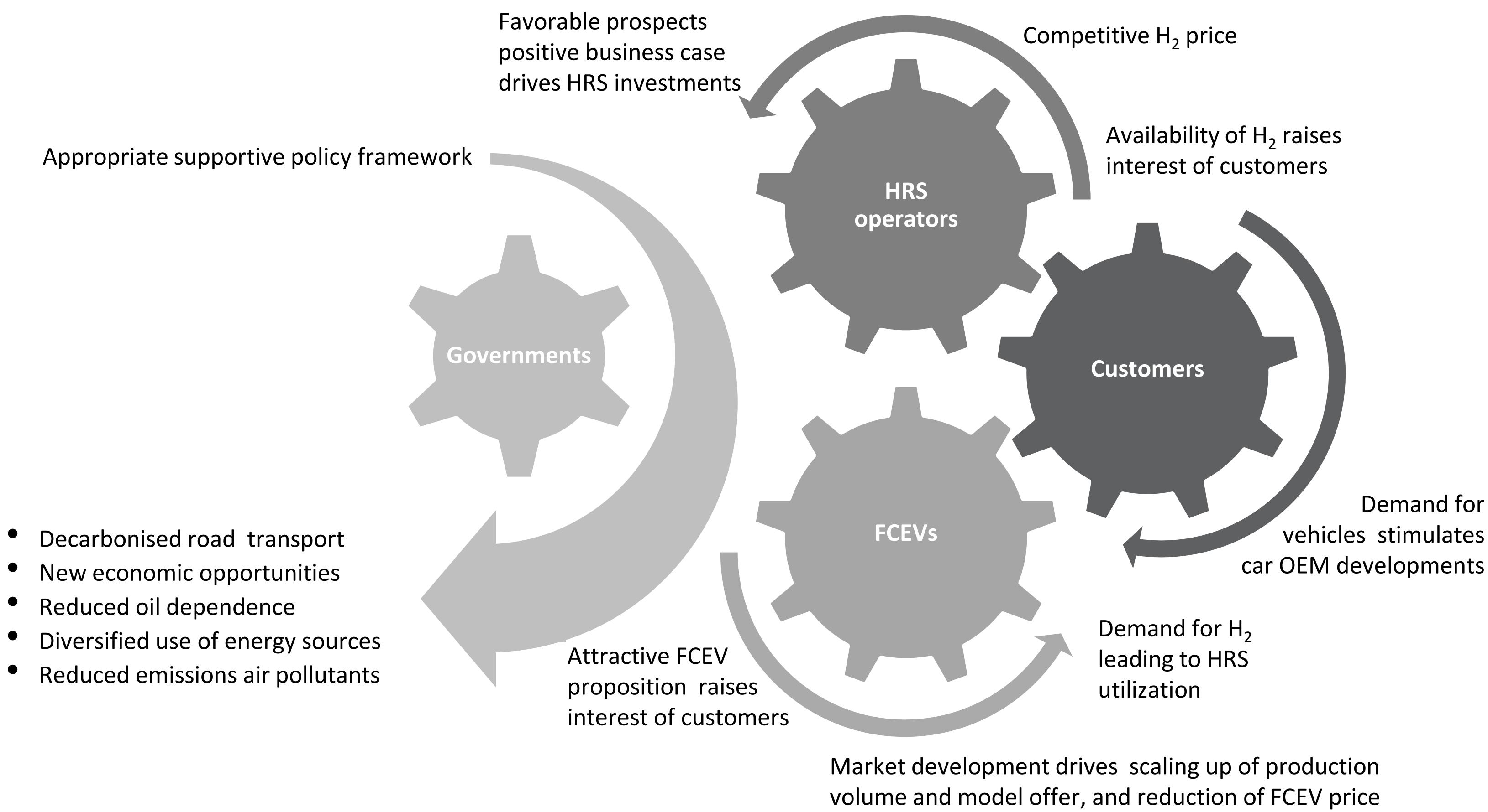
- (Further) reduction of investment costs, e.g. by:
  - R&D aimed at technology improvement and system optimisation
  - Standardisation, which reduces investment risks, and enables obtaining of economies of scale
  - Increased competition from new players and developing of (new) industrial supply chains

- (Further and faster) reduction of expenses for operations and maintenance:
  - R&D aimed at more reliable and more robust technologies and systems

The “valley of death”



Interdependence of stakeholders; how to drive the transition?



Next?

- Further critical review of investment costs and especially O&M costs.

- Further review, and more detailed analysis of rollout scenarios and possibilities to optimise HRS network utilisation.

- Explore impact of hydrogen sales price on market potential of FCEVs. Hydrogen and fuel cells are being promoted as technology well-suited for somewhat largers cars with high annual mileage. In the Netherlands these are typically diesel company cars, but hydrogen pricing based on diesel as benchmark seems problematic. For what market volume is hydrogen a competitive option if priced using gasoline as benchmark? This requires a TCO-approach!

- Determine impact of various scenarios for policy support, e.g.:
  - Impact excise duty exemption; in present analysis no excise assumed up to 2020; what if exemption is granted till 2030?
  - Impact gradual phased introduction of excise duty?
  - Impact investment support, e.g. investment support of 50% up to 2020 followed by a gradual phased reduction to no support in 2025 or 2030